Thermal Effect of Extreme Ultraviolet Pellicle

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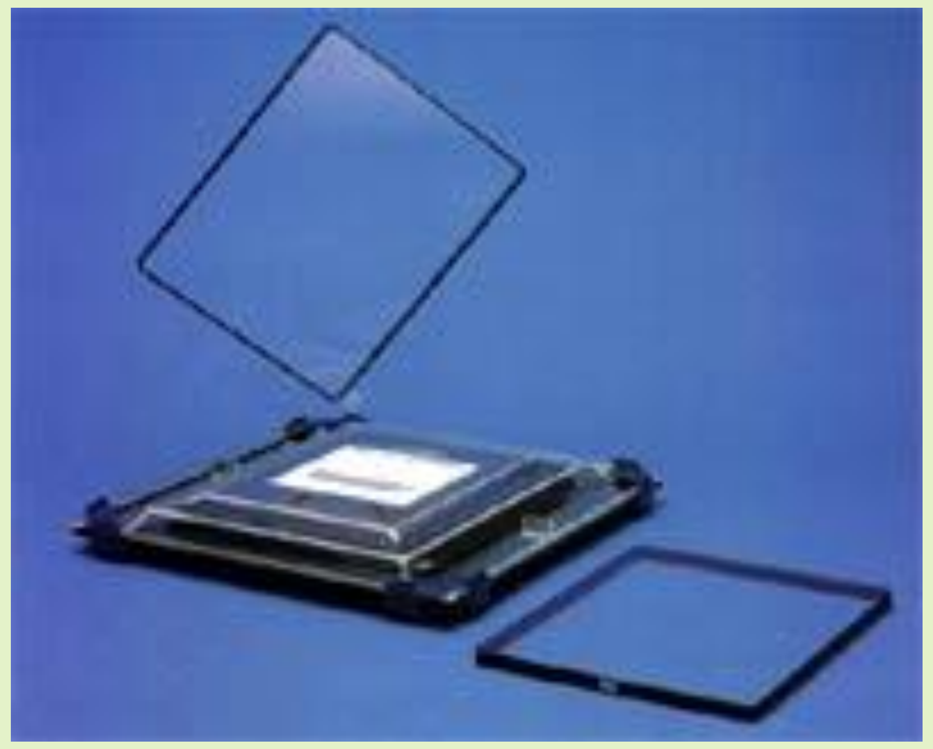
Abstract

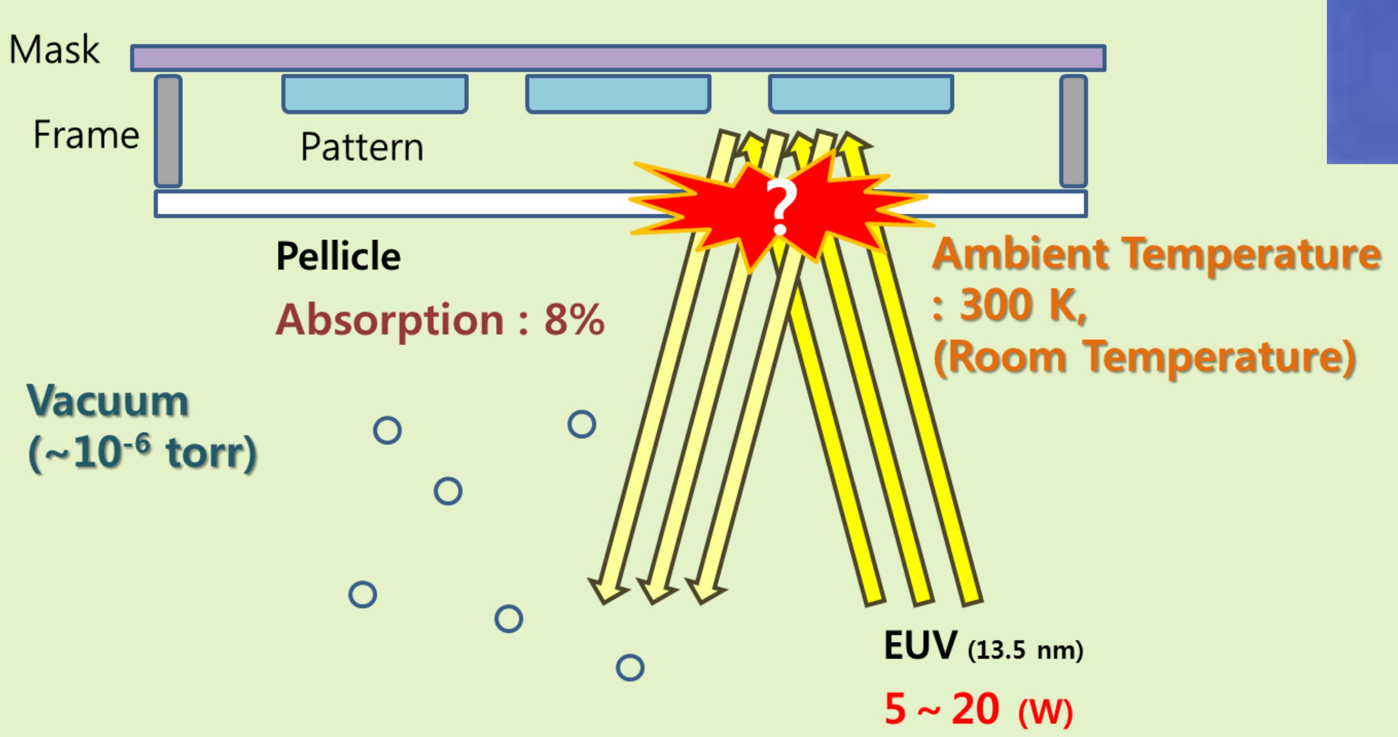
In extreme ultraviolet (EUV) lithography, a pellicle is required to protect a mask from contamination and to increase manufacturing yield. However, the use of the pellicle at the real applications is very challenging since the temperature increase due to EUV light absorption can distort a transmitted EUV beam profile and the image of the mask. Here we report the study of a temperature behavior of the pellicle during EUV lithography based on a simple thermal modeling based on the heat transfer equations. Assuming that radiation is the dominant process for cooling and the pellicle absorbs 16 % of the incident power, the calculated temperature increase of the pellicle is up to ~560 K and the cooling time for the pellicle to the room temperature is ~ 100 ms at the incident EUV light with the power of 25 W and the pulse width of 10 ms. Therefore, the thermal problems of the pellicle can be avoided by optimizing the beam conditions of the EUV light and hence the use of the pellicle is a promising technique in EUV lithography.

EUV Pellicle

<Advantage of the pellicle>

1. Protecting Mask
2. Defocus
3. Production Yield





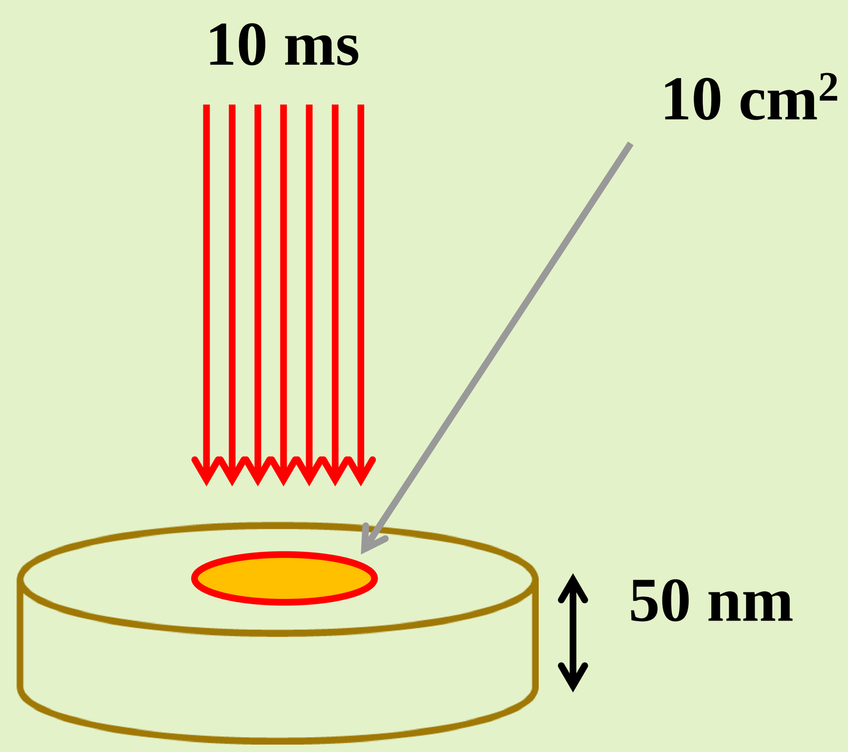
<Obstacles>

1. Thermal load
2. Low transmission
3. Sag (wrinkle)

⇒ **Theoretical modeling for the temperature increase of the pellicle is essential!**

Thermal Modeling I

➤ Heating of the pellicle



Pellicle Thickness	d = 50 nm
Exposure slit Area	A = 10 cm^2
Exposure slit Time	t = 10 ms

Incident Power → P = 5 ~ 25 W

Absorption ratio of the pellicle → 8, 16, 25, 30 %

➤ Cooling of the pellicle

The dominant cooling process is radiation since :

- Conduction : cross-section area is too small.
- Convection : there is no fluid to transfer the heat.

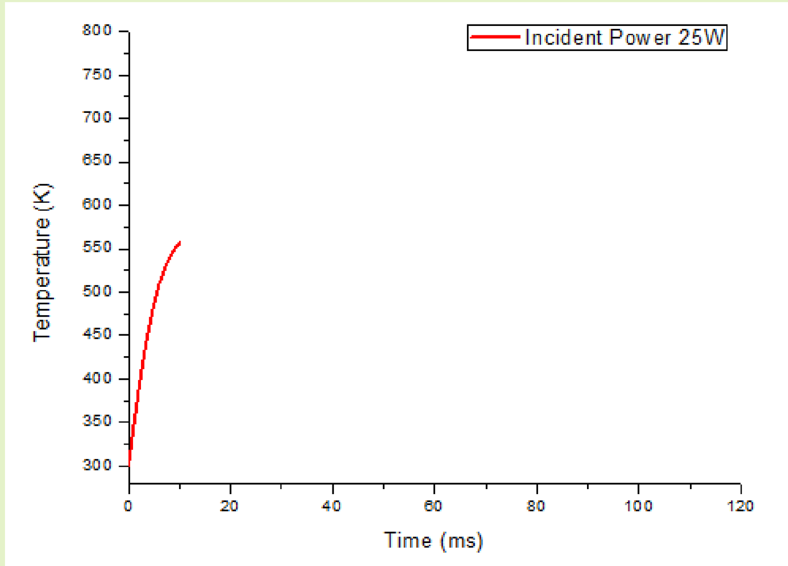
Thermal Modeling II

➤ **The thermal equation used for calculating temperature of the pellicle**

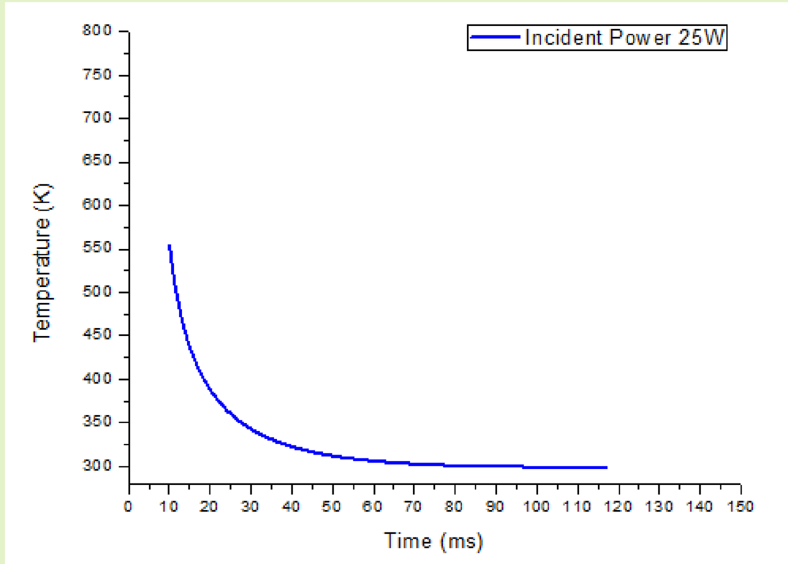
$$c \cdot m \cdot \frac{dT}{dt} = P \; - \; \varepsilon \cdot \sigma \cdot A\left(T^{4} - T_{A}^{4}\right)$$

[Example]

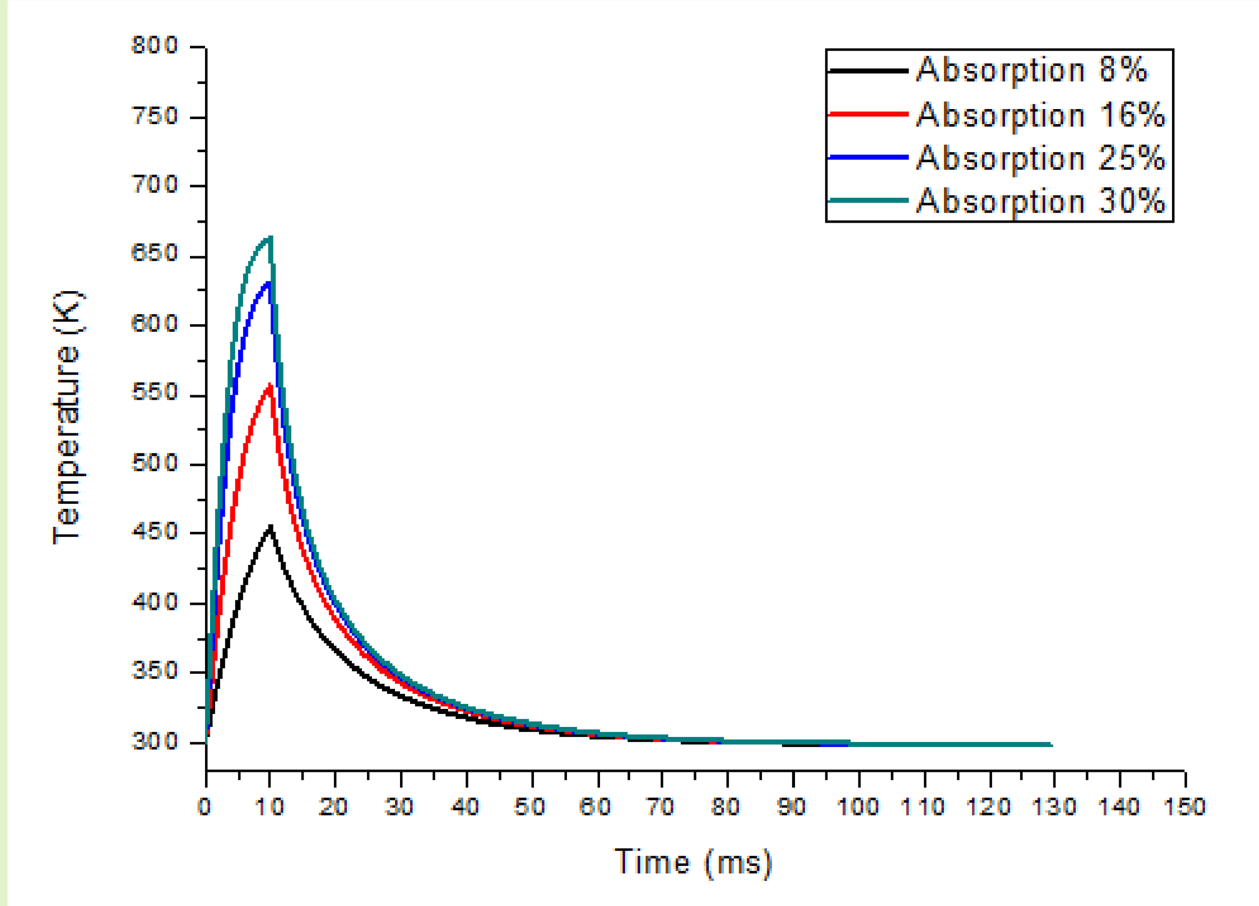
→ In case of heating, P = 25 W
Heating time : 10 ms
Giving in the time value (1, 2, …, 10 ms),
and see how much the temperature rise.



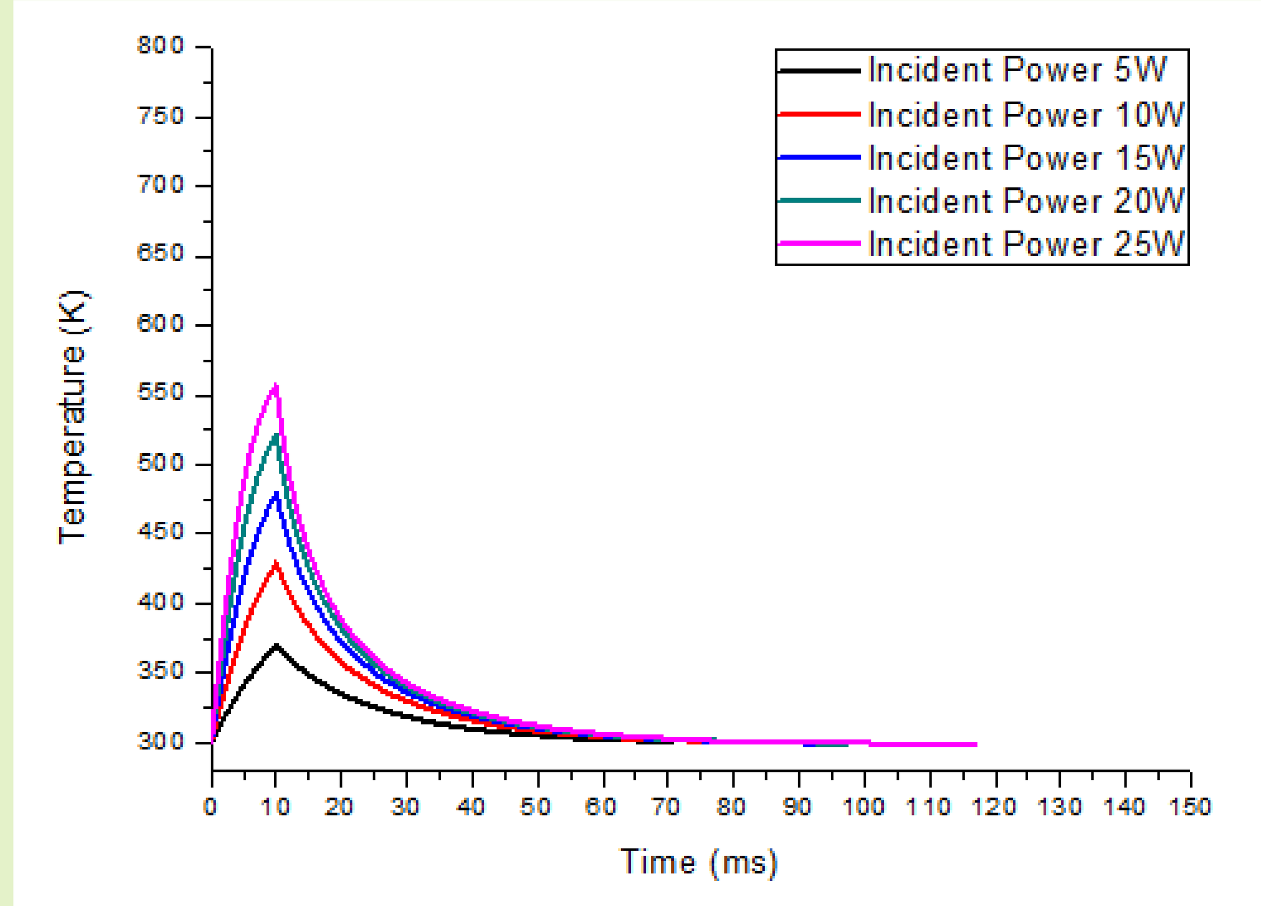
→ In case of cooling, P = 0 W
From the temperature at 10 ms,
getting down the temperature by 1 K,
and see how long does it take for cooling down
to the room temperature.



Results I

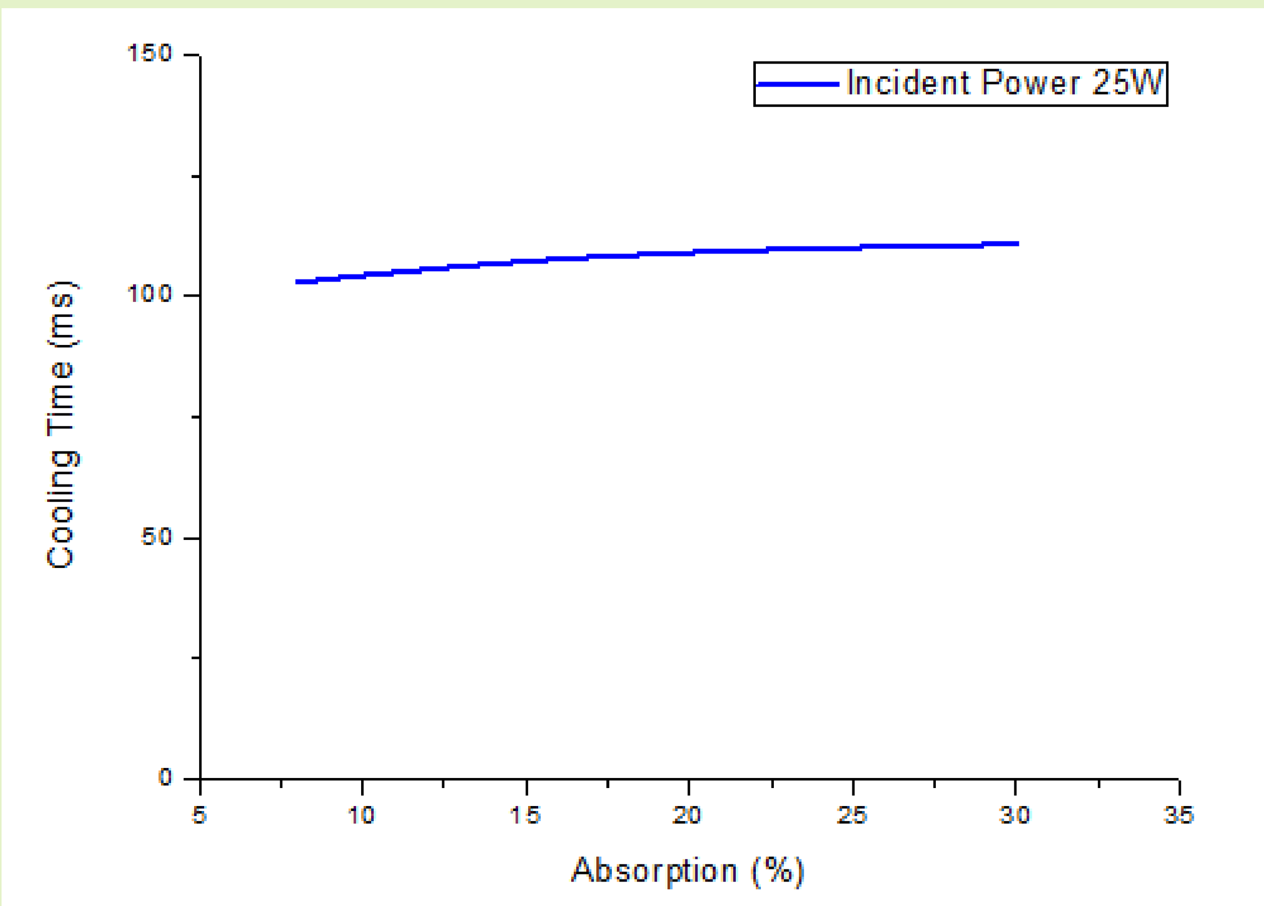


Temperature of the pellicle as a function of time for some absorption ratios at the fixed incident power of 25 W.

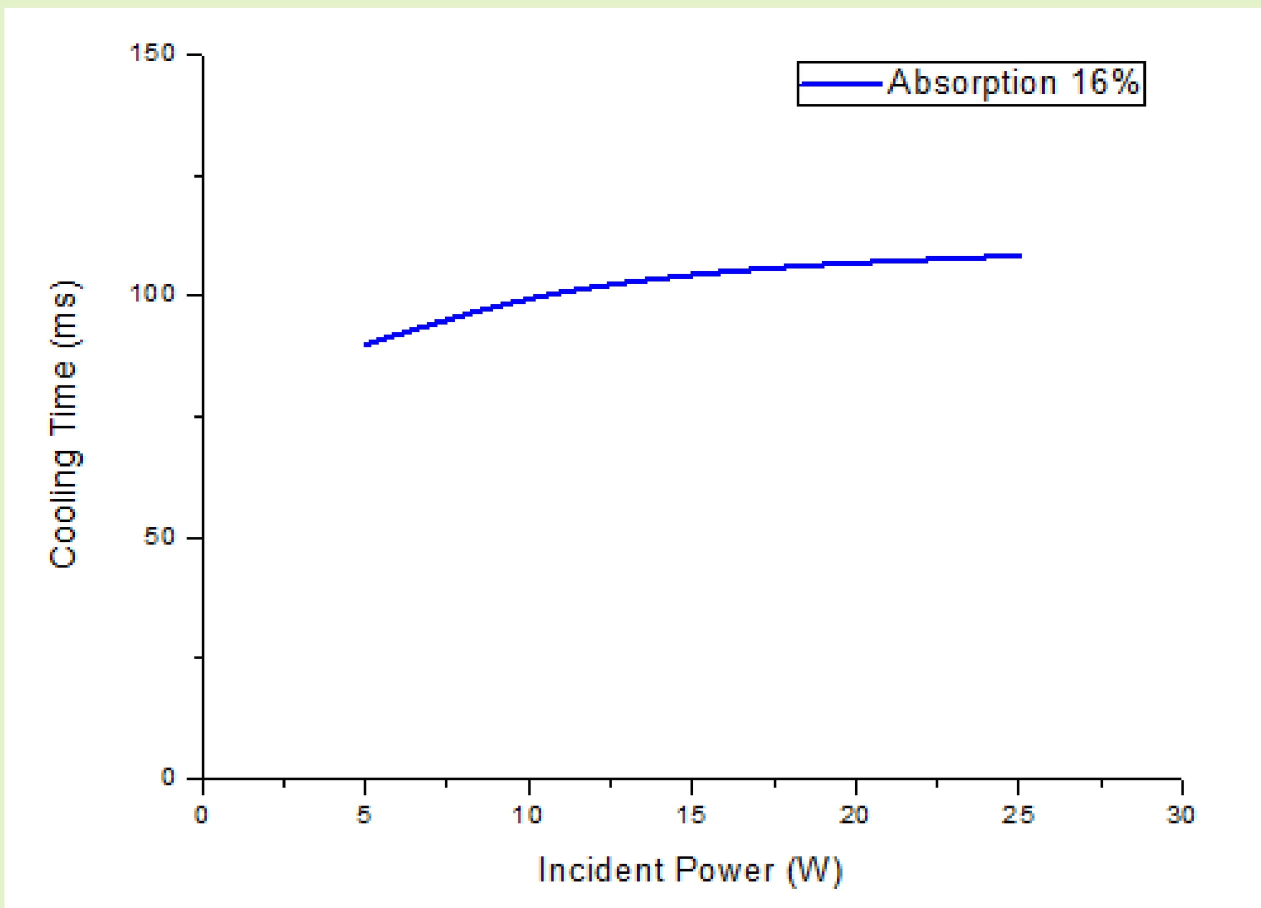


Temperature of the pellicle as a function of time for some incident pump powers at the fixed absorption ratio of 16 %.

Results II



The time required for the pellicle to be cooled down to the room temperature at the fixed incident power of 25 W.



The time required for the pellicle to be cooled down to the room temperature at the fixed absorption ratio of 16 %.

(Cooling time of ~ 100 ms) << (Time interval between EUV exposure)

Conclusions

➤ **The theoretical modeling on the temperature behavior of the pellicle due to the EUV light was carried out based on the heat transfer equations.**

➤ **It is shown that the radiation is the dominant cooling process of the pellicle compared to convection and conduction.**

➤ **The maximum temperature of the pellicle is less than 670 K at the incident EUV power of 25 W with the extremely higher absorption ratio of 30 %.**

➤ **The calculated cooling time of the pellicle does not show any significant increase even for the higher incident power and absorption ratio, which is less than 110 ms. Therefore, if the time interval of the EUV exposure is longer than 110 ms, the thermal problems of the pellicle can be minimized and we do not need to worry about them.**

Future Works

➤ **Further optimization on the thermal modeling considering the localized heating due to the mesh structure.**

➤ **Modeling on the distortion of the pellicle structure due to thermal expansion of the mesh during the heating process.**

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